

Massive Parallelization and Explorative Visualization of Tokamak Gyro-Fluid Turbulence

A Tempest in a Tokamak

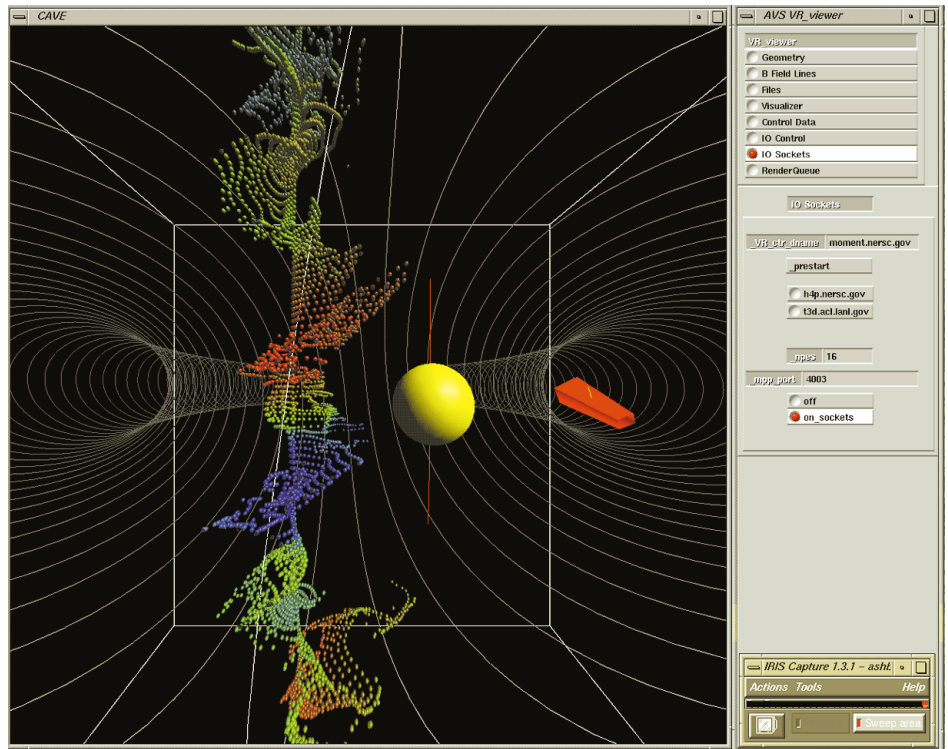
Mission

This research is a part of the Numerical Tokamak Project (NTP), a national consortium to create predictive numerical simulations of fluid plasma turbulence in tokamak fusion experiments using the most powerful supercomputers in the world. Our mission is to use massively parallel computers to simulate the behavior of tokamak plasma and represent the results for scientific visualization and diagnosis.

Impact

Tokamaks are exceptionally expensive, the largest costing in excess of \$1 billion. These simulations will predict the scaling behavior of plasma transport in tokamaks so that we can have confidence in the ultimate performance of these devices for the generation of net electrical power.

The significance of scientific breakeven in fusion cannot be overstated. However, a tremendous amount of development remains before fusion can be applied to the commercially successful generation of electricity. Future machines will likely cost several billions of dollars each. Such machines must be designed to perform optimally, allowing little room for uncertainty.



We have designed an interactive distributed visualization system as an integral part of the computing environment we are using to study tokamak turbulence. Part of the system consists of a (parallel) flow visualizer that advects gyro-fluid elements in the CAVE, an automatic immersive visualization environment, using AVS. The gyro-fluid element trajectory computation is done in real time on multiple parallel supercomputers linked via high-speed networking to the CAVE and uses a distributed database of precomputed flows. The AVS/CAVE system maps the trajectories stereoscopically and provides an interactive interface for user control.

Violently turbulent plasma storms of varied shapes and sizes occurring in current tokamak experiments make it difficult to predict with certainty how any given discharge will behave. High-performance computing will play a profoundly important role in designing these machines. We are finding ways to unlock some of the deeper secrets of this nationally important scientific problem with the enormous increase in computed information allowed by new massively parallel (MP) computing and high-speed communications technology.

Applications

Predictive scaling studies of three-dimensional turbulence in tokamaks such as those represented by this work are important to characterizing and understanding current and proposed experiments. An example of one such issue is how the character

of plasma turbulence changes with the size of the tokamak and with the shape of the electrical plasma current. Strong plasma turbulence in tokamaks increases the mixing of the hot dense plasma in the reactor core, where fusion occurs, with the cooler edge plasma near the reactor wall. Fusion reactors rely on fusion energy released in the core plasma to keep the reaction going. If the hot dense fuel plasma in the reacting core mixes too quickly with the cooler edge plasma, the fusion reaction is extinguished. The massively parallel computers now becoming available can relax the limits that have constrained computational research in this arena for decades. Earlier computer models could represent small- or large-scale disturbances separately but could not simultaneously resolve multiple scales, a key feature of strong turbulence. With massively parallel processing (MPP),

we can study these important physics issues, which could not be adequately addressed in the past.

Redesigning Algorithms

To realize the gains in computational power made possible by massively parallel computers generally requires that algorithms used in traditional serial and vector computers be adapted or redesigned to optimally use a particular target parallel architecture. We have created high-performance parallel algorithms optimized for the CRAY vector MP (C90) and MPP (T3D) architectures for both production physics simulation and visualization.

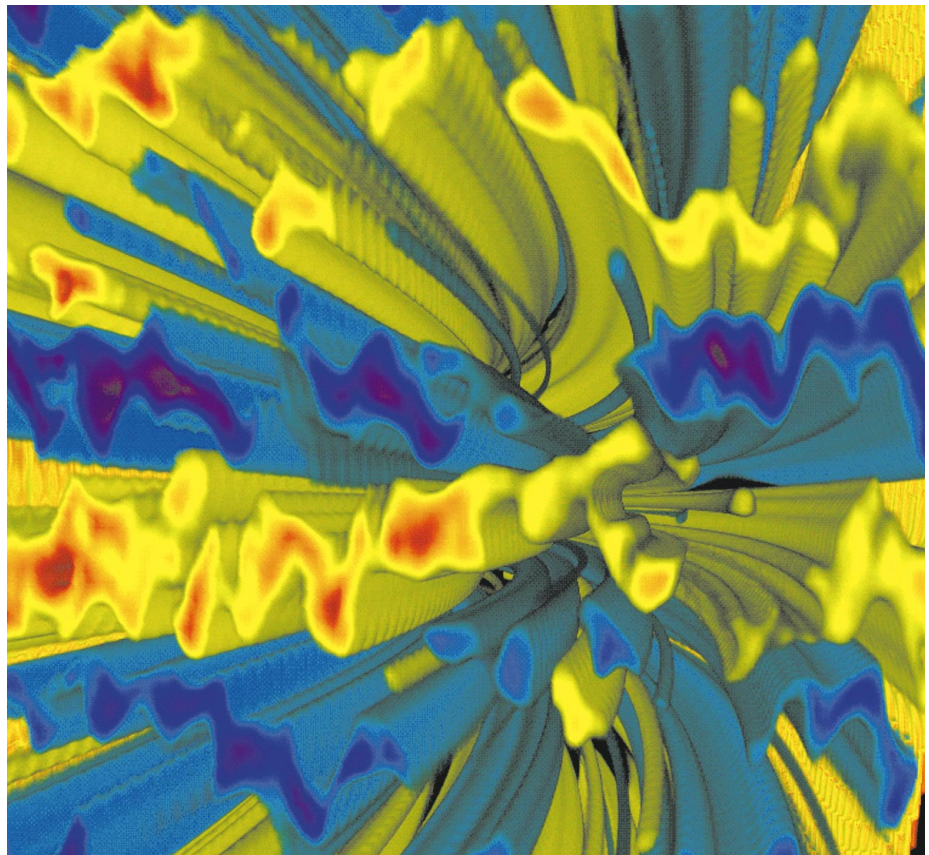
Distributed Scientific Visualization

We have also created a distributed graphics postprocessing system to create and view scientific visualizations from large turbulence simulations. The system coordinates real-time multiple MPP supercomputing interactively with simultaneous presentation in the CAVE virtual reality (VR) theater. (See figure.)

This VR system represents a next step in interactive, three-dimensional explorative visualization for the Numerical Tokamak Project. A principal purpose of this capability for NTP simulation is to provide interactive visual experience to help us understand the convective transport processes operating in tokamak fusion experiments. The hope is that this understanding can stimulate the development of better models for use in designing viable reactors.

Collaboration

At each stage of this research, the most powerful supercomputers and the fastest computer network communications are used. Creating and exercising the simulation code as well as creating and viewing visual-



VOLUME RENDERED ELECTRON DENSITY FOR GYROFLUID ION TEMPERATURE GRADIENT DRIVEN TURBULENCE. The red and blue correspond to counterrotating vortex cell cores aligned with the magnetic confinement field. The turbulent flow causes mixing of hot plasma from the tokamak center with cooler plasma from the periphery. In simple terms, the more strongly the plasma is heated, the stronger the turbulence.

izations of the results all rely heavily on advanced, computer-supported-collaborative-work technology and hardware.

The principal collaborators in this research are plasma physicists specializing in theoretical, computational, and applied experimental plasma physics:

- Gary D. Kerbel, at the Center for Applied Scientific Computing (CASC) at Lawrence Livermore National Laboratory.
- Greg Hammett and Mike Beer, with the Princeton Plasma Physics Laboratory (PPPL) in Princeton, New Jersey.
- Ronald E. Waltz, with General Atomics in San Diego, California.

- William Dorland, with the Institute for Fusion Studies (IFS) at the University of Texas, Austin.
- Dana E. Shumaker, at the Center for Applied Scientific Computing (CASC) at Lawrence Livermore National Laboratory.

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